

**SUMMARY TALK:
CHALLENGES IN PARTICLE ASTROPHYSICS**

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Introduction

At this meeting we had 42 talks which covered most of the important subjects of the field of particle astrophysics. In addition, on one afternoon more details were presented in 5 parallel sessions with another 42 shorter talks.

Particle Physics is very nicely described in terms of the rather complete ‘Standard Model’ with 6 quarks and 6 leptons interacting through the exchange of photons, weak gauge bosons and gluons. So far no significant deviations have surfaced. More and more details have been added to complete the picture and there is no serious hint of a discrepancy that would indicate new physics beyond the Standard Model. Only the “Higgs” is not found yet. But in the last 10 years or so there have been great advances in the field of Particle Astrophysics adding new information to particle physics while simultaneously opening up new windows of observation in astrophysics and astronomy.

1. Neutrino oscillations have been discovered in studies of neutrinos created in energy production in the sun and through cosmic ray interactions in the earth atmosphere. Furthermore, neutrinos from SN 1987 A

have been detected, confirming qualitatively the basic expectations for a supernova explosion. These important discoveries have been impressively confirmed with oscillation observations of neutrinos from power reactors and particle accelerators.

2. Extensive studies performed with radiodetectors on satellites, on balloons and on earth of the 2.7° K cosmic microwave background (CMB) have revealed a flat universe ($\Omega = 1$) and supported by observations of supernova of type 1A out to distances beyond $z = 1$, an energy content of the universe dominated by Dark Energy and Dark Matter with only a smallish fraction in the form of baryonic matter. There is also a contribution of neutrinos with mass, although apparently on an even much smaller level.
3. TeV gamma ray experiments have detected by now more than 40 sources, mostly of galactic origin but 10 are obviously from extragalactic sources.
4. Searches for diffusive neutrinos from SN-explosions and for diffuse infrared photons, both cosmological signals, have resulted in only upper limits up to now but close to expected levels with prospects of real observations in the next future.
5. Searches for gravitational waves enter a new phase with the interferometers LIGO, GEO600, VIRGO and TAMA taking regular data and pushing background levels close to expectations.
6. Searches for Dark Matter candidates approach sensitivity levels that significantly constrain properties of new particles and of extreme astrophysical objects.

These success stories drive further developments of the field that is based most importantly in very fundamental questions and problems formulated long ago by great scientists in the somewhat distant past. To name a few: Max Planck (1899), Victor Hess (1912), Albert Einstein (1916), Wolfgang Pauli (1930), Fritz Zwicky (1933), Ettore Majorana (1937), Peter Higgs (1962), Kenneth Greisen, Georgiy Zatsepin and Vadim Kuzmin (1966), Andre Sakharov (1967), Bruno Pontecorvo (1968); of course a rather incomplete list.

Let me now try to cover some of the essentials of presentations at this meeting, all on items at the forefront of particle astrophysics.

1 Is there a Cutoff in the Allparticle CR – Energy Spectrum?

The most recent high statistics data come from the high resolution fly’s eye (HIRES) experiment. Overall there is within the limits of the systematics rather good agreement with previous experiments. However, the data show two features, firstly a shallow dip at $\log_{10}(E)(eV) = 18.6$, most likely due to e^+e^- pair loss of protons and an apparent cutoff at $\log_{10}(E)(eV) = 19.6$ due to single pion photoproduction. Both effects are consistently understood in terms of interactions of primary protons of extragalactic origin with the $2.7^\circ K$ cosmic microwave background.

New experiments like Telescope Array in Utah and most importantly the AUGER experiment in Argentina are both much larger than previous arrays. However, by combining the two techniques of scintillator (Cherenkov) stations on the ground with the observation of the fluorescence light of the airshowers, one expects to improve not only on statistics but in particular on the otherwise dominating systematic uncertainties.

Based on the prediction by Askarian (1962) of detectable radio signals from shower development in rock and ice, new experimental possibilities open up, since in particular the acceptance area can be increased dramatically. One aims for the detection of radio signals coming from high energy neutrino interaction in antarctic ice (ANITA) or even in moon rock (Nu-Moon). The aim is of course GZK neutrinos that would consist of a beautiful new cosmological signal due to cosmic ray protons interacting with $2.7^\circ K$ photons everywhere in the distant universe, as expected from the most straightforward interpretation of the HIRES result.

2 Dark Matter

One obvious interpretation of rotation curves of spiral galaxies is the existence of astronomical objects of subsolar mass which can be detected through their action as gravitational lenses on background stars. Two larger collaborations, MACHO and EROS, observed millions of stars in the large (small) ‘Magellanic Clouds’ to search for lensing events due to dark objects. The result of this monumental effort is now quite convincing; so called MACHOS in the mass range (10^{-7} – a few) solar masses do not provide for the dark matter of our galaxy, all observed lensing events are of known origin, new dark astronomical objects are not required. Too bad.

New extended observations of dwarf spheroidal galaxies in the more lo-

cal environment of our galaxy, some of them only recently discovered, in large ongoing surveys, e.g. SDSS. Large telescopes of the 8 – 10 meter class, equipped with multi object spectrographs, have allowed for detailed studies of the dynamical behaviour of stars in dwarf ellipticals. The results are very puzzling, the galaxies seem to be dominated by dark matter, but all with about 4×10^7 solar masses in DM, despite quite a range in mass/light. In standard models, where large galaxies result from merging many smaller ones over cosmic time one would expect to see at least in some of them (strong) tidal effects, but this is not what is observed. Also alternative theories like e.g. MOND seem to fail. On the other hand MOND is very successful in describing rotation curves of spiral galaxies, small and large, in even fine detail. And MOND has somehow become more acceptable since a relativistically invariant version, TeVeS, with classical MOND as the nonrelativistic limit has been found by Bekenstein (2003). The dynamical behaviour of galaxies in clusters, however, cannot be quantitatively described by MOND, massive neutrinos of cosmological origin with mass of about 2 eV (at least one species) might cure the defect.

Will laboratory efforts be more successful? Over the last 20 years there have been great advances in the suppression of background, by roughly a factor of 10^6 . But also new ingenious detection methods have been developed. No convincing dark matter candidates (Wimp) have been found so far. So the trend is for larger detector masses without compromising the background level. The aim is to come below scattering cross section levels for mass ranges indicated by e.g. supersymmetric extensions of the standard model. Will classical particle physics, in fact LHC, provide candidates? Even if that's the case they still need to be observed in DM-search experiments outside accelerators to solve the DM-enigma of astrophysics.

3 Low Energy Neutrinos

Neutrinos already show a rather complicated phenomenology and very much is still to be discovered. Of foremost importance is a measurement of theta (1,3) which is certainly much smaller than both theta (2,3, 1,2). To get a value for the (1,3) mixing angle large efforts are required and several experiments are underway. Double Chooze may be next with a result but if they get a limit only (pessimistically), at least the large scale multinational effort at Daya Bay is needed. A small value of theta (1,3), however, will make it very hard to find CP violation effects. It sounds like a long way still. But it must as well be admitted that any reasonable understanding of

the mass spectrum of (elementary) particles seems far below the horizon. In particular: why are neutrino masses so small? Indeed, at this meeting we heard the phrase “there is a problem of mass”, quite strongly expressed by several speakers.

4 Early Universe

At least back to MeV temperatures where nucleosynthesis happened we think we have a pretty complete and consistent picture of the development of the universe. But there are still some irritating results. It seems rather difficult to fix the ${}^4\text{He}$ content in the universe with sufficient precision, ${}^2\text{H}$ measurements are only very few and in particular the level of ${}^7\text{Li}$ did not fit by about a factor of 2. It is observed in old metal deficient stars and recently it has been claimed that diffusion plus turbulent mixture may account for about this factor of 2 reduction of ${}^7\text{Li}$. But then a new problem seems to appear, ${}^6\text{Li}$ in old stars may be much too abundant to be of primordial origin.

While CMB observations are a beautiful quantitative tool for cosmology by now and with even better observations to come (Planck satellite) one may pose the question – is the light element production casting doubts on the correct understanding of the early universe?

5 TeV Gamma Astronomy

In the ‘90ties both Whipple and HEGRA made ground breaking discoveries in the particle astrophysics field. The overwhelming drive comes from the attempt to solve the question of the origin of cosmic rays. High energy TeV sources were discovered, galactic and extragalactic. Two new experiments, H.E.S.S. in Namibia and MAGIC on La Palma are follow up experiments of HEGRA. Both are very successful and lead the field by now. Larger mirrors and large acceptance cameras led to the discovery of many new sources, mostly located inside our galaxy. The source number count is now more than 40. At least 5 different classes have been established, SN remnants, binary star systems, extended emission regions and pulsars. The extragalactic sources are all Blazars, a special subclass of active galactic nuclei (AGN). Further M87, long suspected to be an important extragalactic contributor to cosmic rays, has by now been firmly established. Photon energy spectra extend up to nearly 100 TeV. Energy spectra from Blazars have allowed for a strong constraint on the intergalactic (infrared) photon field to a level just compatible with the results from galaxy counts. No extra sources seem to

be required and earlier larger contributions to the infrared photon flux seem now rather safely excluded.

6 Planck Mass

In discussions of attempts to get a theory of quantum gravitation the Planck Mass M_{Pl} sets the scale in a number of relations. It is appropriate I think, to go back and have a look at the original publication of Planck which appeared in the ‘Sitzungsberichte der preußischen Akademie der Wissenschaften’ in 1899. Planck gave a series of five reports “über irreversible Strahlungsvorgänge” (on irreversible radiation events). §26, the last paragraph of the whole series, has the title “Natürliche Masseinheiten” (natural units). Here he introduces fundamental units for length, time and mass (and temperature) as combinations of the gravitational constant (f), the velocity of light (c) and a constant (b) which today is Planck’s h , that he introduced in the foregoing reports. His considerations are truly astonishing as he argues that these units are independent of specific bodies or substances and keep their meaning for all times and for all, even extraterrestrial and nonhuman cultures, as long as the laws of gravitation, light propagation in vacuum and both laws (Hauptsätze) of the theory of heat remain valid. Determined by even very different intelligent beings they have to have the same values. Did he read Jules Verne?

Finally, I cannot resist to comment on the name of a new all purpose underground laboratory discussed by B. Sadoulet, “DUSEL”, actually a proper German word with the meaning fluke (somehow undeserved).

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